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The Role of Electrical Resistance Tomography in the U.S. Nuclear Waste Site Characterization Program

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The Role of Electrical Resistance Tomography In the U.S. Nuclear Waste Site Characterization Program

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Abstract- Several tests are being conducted in the densely welded Topopah Springs tuff within Yucca Mountain, Nevada to study the thermomechanical and thermo-hydrological behavior of this horizon and its suitability as a potential storage unit of the high level nuclear waste for the USA. One of the methods used to monitor the hydraulic response of the rockmass is electrical resistance tomography (ERT). We will describe one of these tests, the drift scale test, to describe and illustrate the role that ERT has played during that work.

1. INTRODUCTION

The United States Department of Energy (DOE) is investigating the suitability of Yucca Mountain as a potential site for the nation's first high-level nuclear waste repository. The site is located about 120 km northwest of Las Vegas, Nevada.

Favorable aspects of Yucca Mountain as a potential repository site include its arid nature and the sorptive properties of the rock material. The arid environment results in unsaturated conditions at the potential emplacement horizon, which is the Topopah Spring Tuff of the Paintbrush Group. The major advantages of unsaturated conditions are that container corrosion, waste-form leaching, and radionuclide transport mechanisms are minimized because there is less available water to contact the waste package.

Because a repository is required to isolate radioactive wastes for long periods of time, the evaluation of that isolation is unprecedented. Specifically, evaluation must be made of the isolation potential of the repository system composed of both natural and engineered components, for a minimum of 10,000 years, but times could extend up to a million years. Processes that must be considered include hydrologic processes in unsaturated fractured porous rock, which is poorly understood, further complicated by the significant processes that will result from the introduction of heat generated by radioactive decay of the waste.

Because of the long time frames that must be evaluated, it will be impossible to directly measure the performance except for very small portions of the entire waste/natural system interactions. Therefore, analysis based on conceptual models using computer codes to evaluate or predict the performance will be the basis for determining the potential for the repository to properly function (that is, to provide isolation) over the long times required. Such an analysis entails more than merely achieving a scientifically believable view of the repository. It must provide sufficient rigor in evaluation of the models and assumptions to be useful in a regulatory process wherein the analysis will be subject to challenge by those opposed to the project. Thus, the models need to be tested and verified to the extent possible.

A testing strategy has been developed that is designed to evaluate the models by accelerating portions of the testing to address different segments of the time frames of interest and to look at the functional relationships of different geometric scales. Because no single test can address all of the issues several different test approaches are being used to assess the models. The types of test, identified in order from the smallest geometric scale to the largest, and generally from the shortest duration to the longest, fall into the following categories:

1-Laboratory tests of core-size samples. These are tests to measure matrix properties and processes and properties of single fractures. The duration of such tests is usually a few hours or days.

2-Laboratory tests of approximately 1 m scale block samples (small block tests). These samples are large enough to allow testing of fracture properties, the effects of discontinuities and even some multiple-fracture responses. They provide an understanding of the processes of a fractured rock and enable the development of functional relationships in terms of the influence of scale.

3-Field tests on large blocks of approx. 4 m scale. These tests are critical because of the sufficient size to incorporate a fracture system that is representative of the distribution of fracture dimensions and characteristics that would likely be in a repository—with the possible exception of major geologic structures, such as faults. A single test of this scale has been conducted.

4-In situ tests of scale tens of meters. These are relatively large tests that involve hundreds of cubic meters and extend for many months or years. They incorporate sufficient volumes of rockmass to be representative of total rock-mass responses. These tests have boundary conditions that are poorly controlled and thus are focused more on hypotheses testing for processes that are scale-dependent and on characterization of repository rock behavior. Whereas these tests last several years, they are nonetheless highly accelerated, in comparison with the rates and processes expected in an actual repository.

5-Confirmation tests. These tests do not involve issues of scale, because the actual repository and its associated process rates will be monitored. Thus one of the purposes of such testing is to confirm that the testing performed at smaller scales and abbreviated time frames accurately reflect or predict the behavior of the system.

Of course, many techniques are used to monitor conditions in these various tests depending on the time and spatial scale of the test and the limitation of the measurement method. One method, which has been used in several of these tests, is electrical resistance tomography (ERT). We describe here use of ERT in the most ambitious test to date, the Drift Scale Test (DST) which is an in situ test of type 4 described above. This test is being conductrd in the Exploratory Studies Facility within Yucca Mountain.

2. THE DRIFT SCALE TEST

The major objective of the DST is to study the coupled thermal-hydrologic-chemical-mechanical processes at the potential repository's horizon. Several different measurements are being made by researchers at Lawrence Livermore National Laboratory (which include electrical resistance tomography and neutron logging) to determine movement of moisture, measure gas and water geochemistry, and to analyze the temperature the field in the rock. In support of these field activities, thermohydrologic modeling is also being done.

The drift scale test is located about 2.83 km in from the North Portal of the Exploratory Studies Facility (ESF). The configuration of the DST is shown in Figure 1. The heated section of the test drift is nominally 47.5 m long and houses 9 floor heaters along its centerline. In addition, fifty wing heaters are uniformly spaced in 11.5-m deep boreholes drilled into the 2 side walls of the heated drift (HD). The total heat output available for the floor and wing heaters is approximately 68 kW and 143 kW, respectively. The test design calls for four years of heating, which calculations indicate will create a dry zone around the heated drift extending approximately 10 m into the surrounding rock. During the heating phase, drift-wall temperatures should not exceed 200°C. Heating of the drift began on December 3, 1997.

3. ELECTRICAL RESISTANCE TOMOGRAPHY and MOISTURE CHANGES

Eight boreholes, containing a total of 140 ERT electrodes, were drilled above and below the HD to form vertical planes parallel to the drift. An additional 4 boreholes, containing 60 electrodes, form vertical planes at right angles to the HD. Images of resistivity change were calculated using data collected before and during heating. The placement of these boreholes is shown in Figure 1. Many other boreholes, not shown here, were used for other instrumentation such as resistance temperature devices.

We use ERT to map the changes in moisture content caused by the heating of the rock mass. Of special interest is the behavior of liquid water, with an emphasis in the movement of condensate out of the system. Of course, changes in resistivity, which ERT can measure directly, are caused by changes in both temperature and saturation (and probably pore water ionic strength, although we will assume it does not change). The Waxman and Thomas [1] model has been used to calculate rock saturation after accounting for temperature effects [2].

Figure 2 shows the saturation change estimates made from the ERT images along the axis of the HD. These results suggest that most of the drying is occurring above the HD where the maximum drying is about two thirds of the original water (saturation ratio of about 0.3) by early June 1998.

Figure 3 shows the saturation change estimates made from ERT images taken in a plane perpendicular to the axis of the HD, near the middle of the drift length. Dehydration around the wing heaters is most obvious although there is also drying adjacent to the main drift. In June 1998 the pattern of drying appears to be affected by inhomogeneity (probably fractures) in the rockmass.

This test is in progress and will continue for many more months of heating before a planned cooldown phase. All the data being gathered, including that from ERT, is being analyzed but is also being archived for future use.

4 REFERENCES

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[2] Ramirez, A., and W. Daily (1997). *Electrical Resistivity Monitoring of the Thermomechanical Heater Test in Yucca Mountain.* Milestone report for the CRWMS Management and Operating Contractor, U.S. Department of Energy. (SP9215M4) Livermore, CA: Lawrence Livermore National Laboratory.

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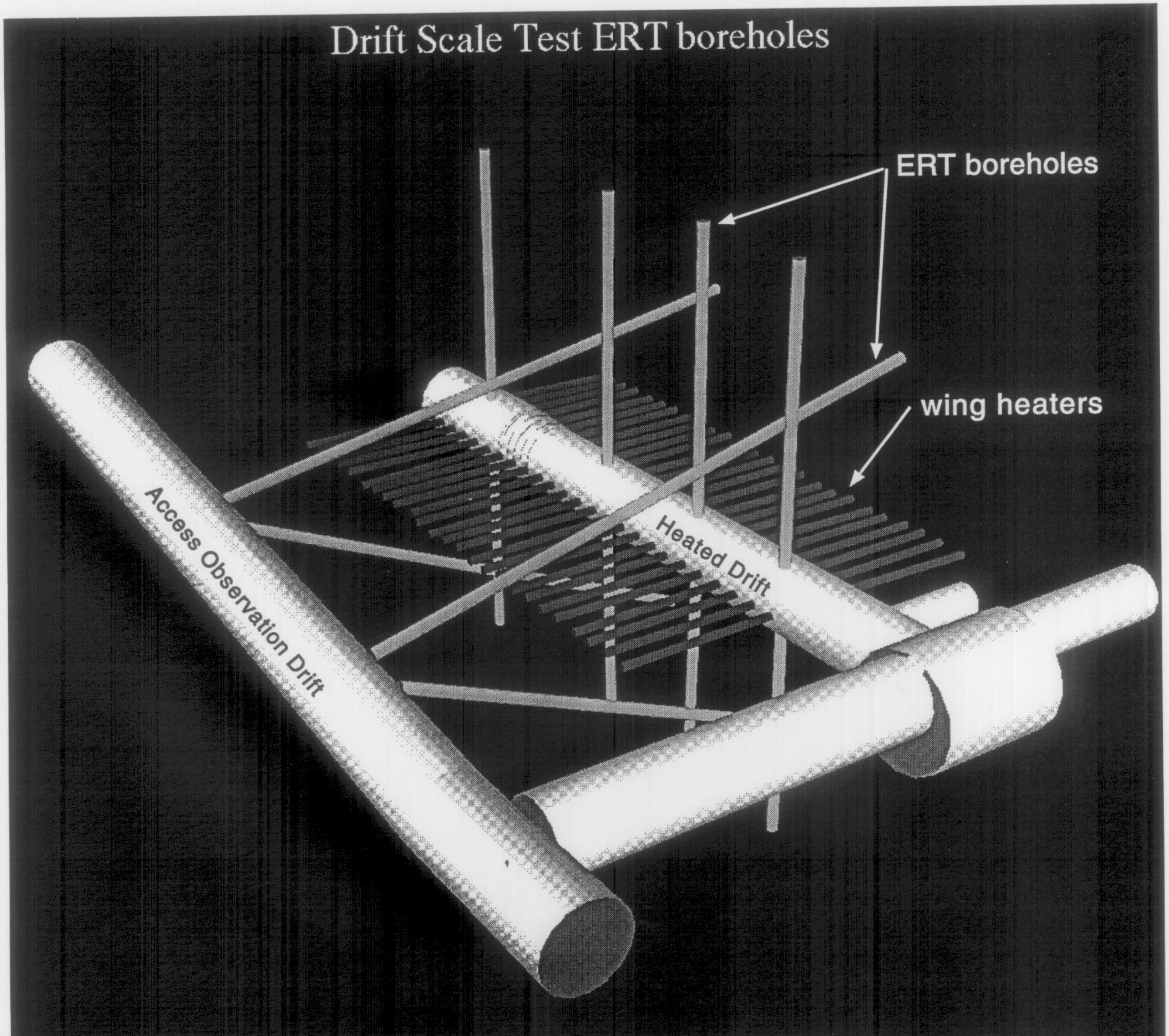
Figure 1. The Drift Scale Test layout in the Exploratory Studies Facility. A thermal bulkhead isolates the 47.5 m heated drift from the connecting drift and the access observation drift. The 12 boreholes used for ERT are also shown, 8 drilled from the heater drift and 4 drilled from the access observation drift.

Figure 2. Maps of saturation change ratio from the 4 ERT planes above and the 4 planes below the heater drift. If the saturation does not change from baseline, the ratio would be 1.0 and if the saturation decreased it would be less than 1.0.

Figure 3. Maps of saturation change ratio from the 2 ERT planes perpendicular to the heater drift. The saturation scale is the same as for Figure 2.



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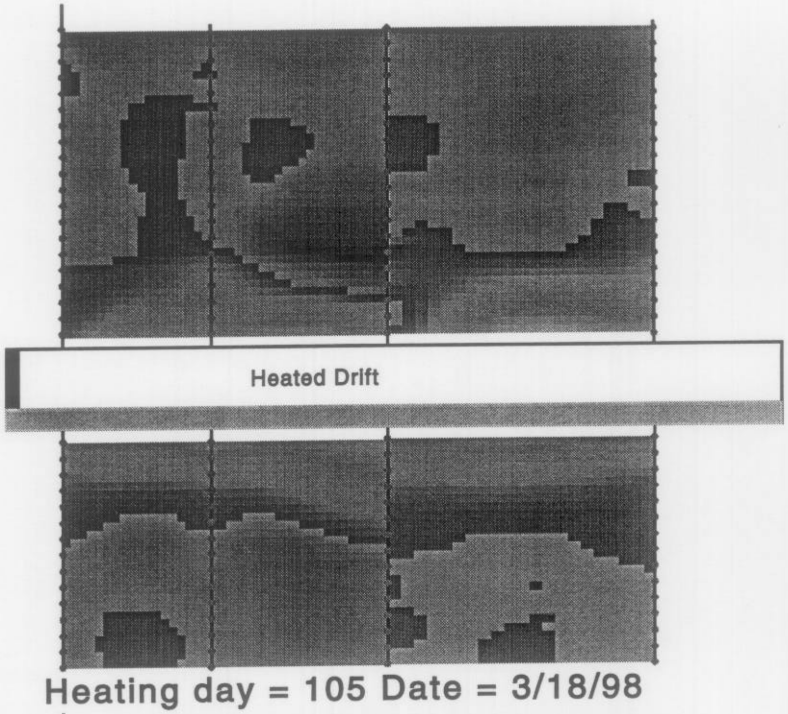

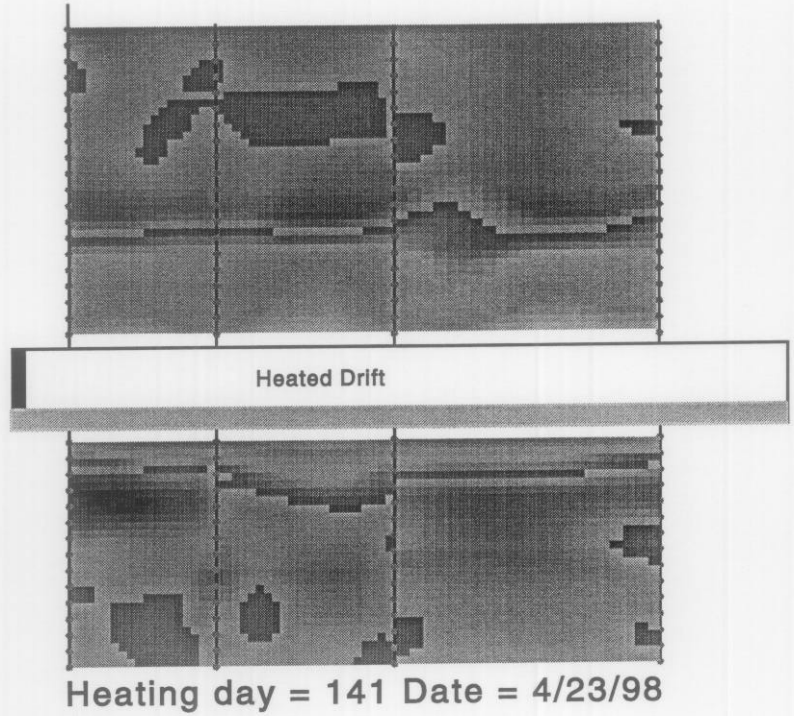

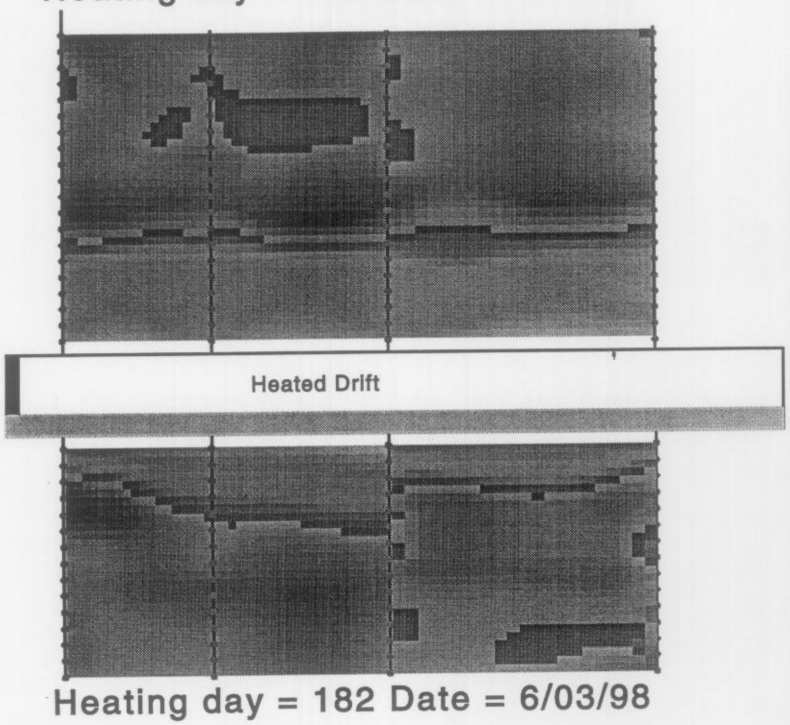

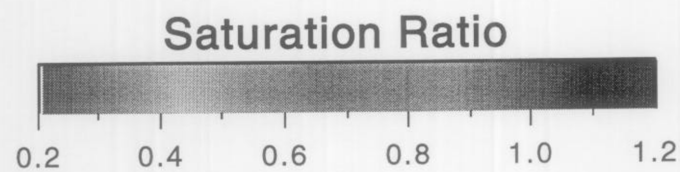

Figure 2. Maps of saturation change ratio from the 3 ERT planes above and the 3 planes below the heater drift. If the saturation does not change from baseline, the ratio would be 1.0 and if the saturation decreased it would be less than 1.0.

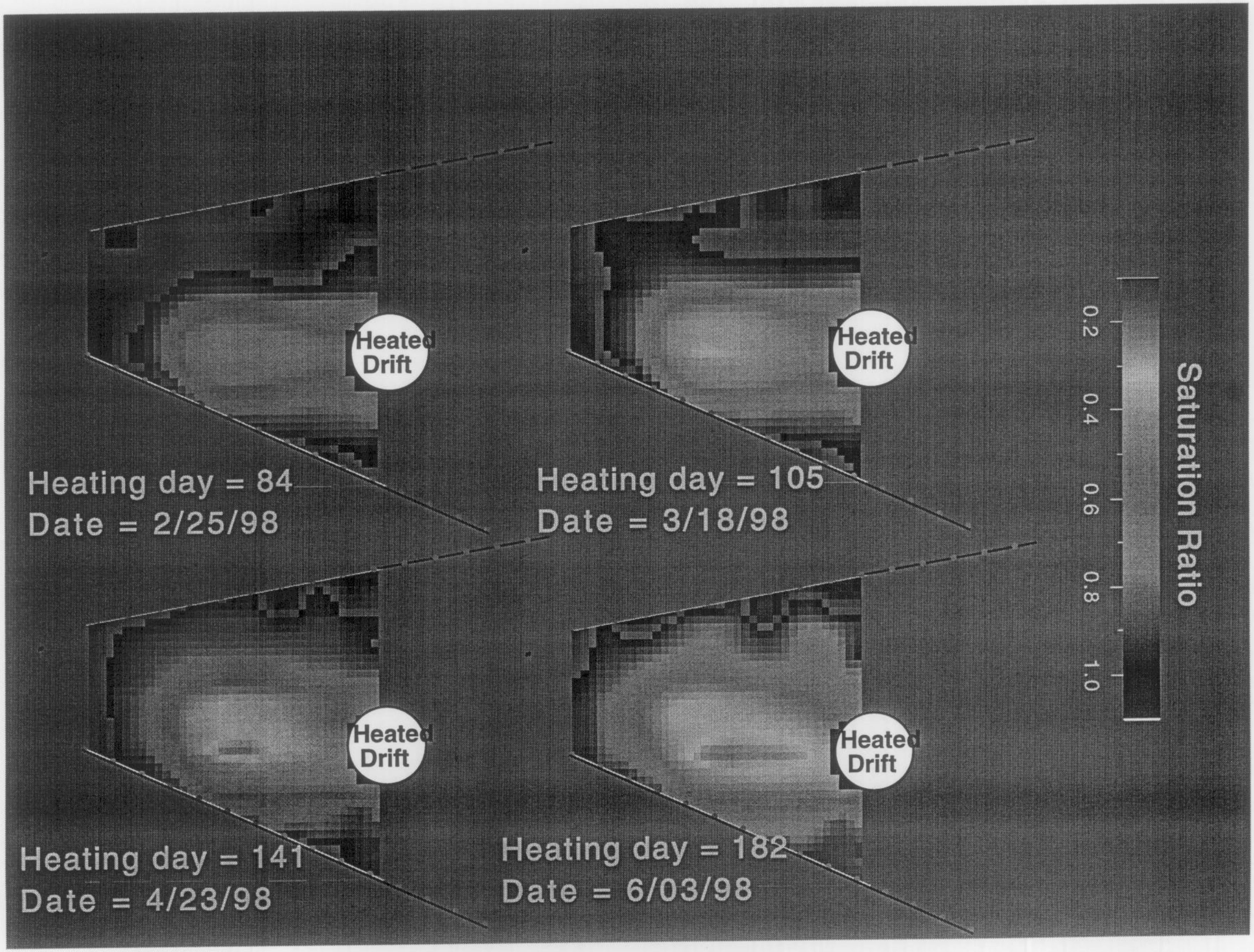

Figure 3. Maps of saturation change ratio from one of the 2 ERT planes perpendicular to the heater drift. The saturation scale is the same as for Figure 2.